Name:

Student ID Number:

Section:

Lecturer: Dr Azni Wati/ Dr Fazrena Azlee/ Dr Jehana Ermy/ Dr Jamaludin

Table Number:

UNIVERSITI TENAGA NASIONAL

College of Engineering

Department of Electronics and Communication Engineering

Test 2 – MODEL ANSWERS

SEMESTER 1, ACADEMIC YEAR 2015/2016

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**22 August 2015**
Time Allowed	:	**1 hour 45 minutes**

Instructions to the candidates:

1. Write your Name and Student ID number. Circle Lecturer for your section.
2. Write all your answers using pen. **DO NOT USE PENCIL** except for the diagram.
3. **ANSWER ALL QUESTIONS.**
4. **WRITE YOUR ANSWER ON THIS QUESTION PAPER.**

NOTE: DO NOT OPEN THE QUESTION PAPER UNTIL INSTRUCTED TO DO SO.

☺ **GOOD LUCK!** ☺

Question Number	Q1	Q2	Q3	Total
Marks				

Question 1 **[40 marks]**

(a) The differential amplifier shown in **Figure 1** has a pair of pnp bipolars as input devices and a pair of npn bipolars connected as an active load. The circuit bias is $\boldsymbol{I_Q}$ **= 0.15 mA**, and the transistor parameters are β **= 100**, and $\boldsymbol{V_A}$ **= 100 V**.

(i) **Draw** the active load circuit to complete the circuit in **Figure 1**. [6 marks]

(ii) **Find the open-circuit** differential-mode voltage gain, $\boldsymbol{A_d}$. [8 marks]

(iii) **Calculate** the value of a load resistance $\boldsymbol{R_L}$ connected to the output $\boldsymbol{v_O}$ if the differential-mode voltage gain $\boldsymbol{A_d}$ **is to be reduced to 524 V/V**. [6 marks]

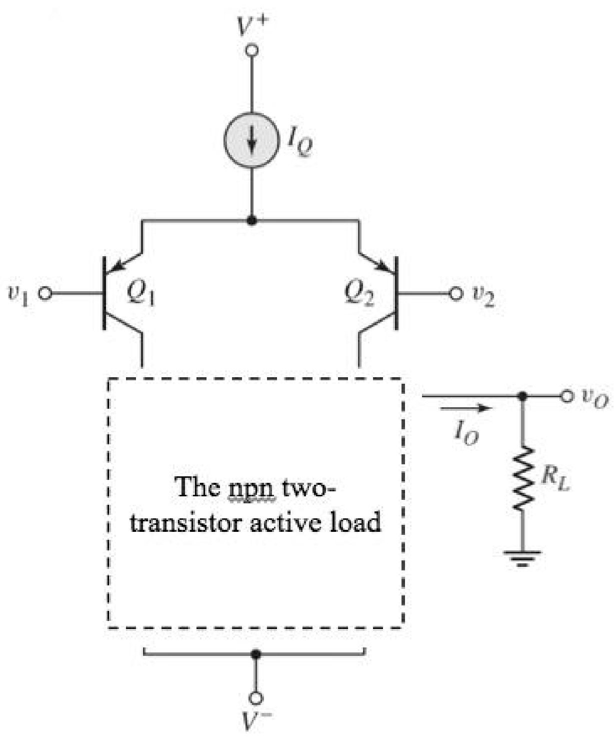


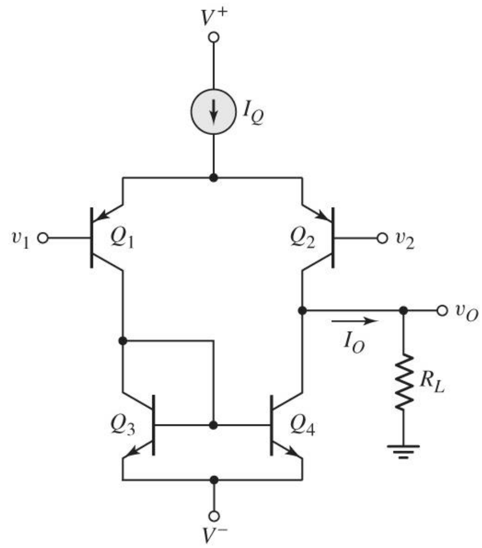
Figure 1

Answer for Question 1(a)(i)

Answer for Question 1(a)

Answer for Question 1(a)

Q1(a)(i)



3 marks: correct label
3 marks: correct placement

Q1(a)(ii)

$$r_{o2} = \frac{V_A}{I_{CQ2}} = \frac{V_A}{I_Q/2} = \frac{100}{0.15m/2} = 1.333M\Omega \quad [2]$$

$$r_{o4} = \frac{V_A}{I_{CQ4}} = \frac{V_A}{I_Q/2} = \frac{100}{0.15m/2} = 1.333M\Omega \quad [2]$$

$$g_{m2} = \frac{I_{CQ2}}{V_T} = \frac{I_Q}{2V_T} = \frac{0.15m}{2(0.026)} = 2.8845mA/V \quad [2]$$

$$A_d = g_{m2}(r_{o2} \parallel r_{o4}) = (2.8845m)(1.333M \parallel 1.333M) = 1923 \quad [2]$$

Q1(a)(iii)

$$A_d = g_{m2}(r_{o2} \parallel r_{o4} \parallel R_L) \quad [2]$$

$$524 = (2.8845m)(1.333M \parallel 1.333M \parallel R_L) \quad [2]$$

$$R_L = 250k\Omega \quad [2]$$

(b) For the differential amplifier **with cascode active load** in **Figure 2** it is given that the circuit parameters are: V^+ **= 3 V,** V^- **= –3 V,** and I_Q **= 1 mA**. **NMOS** transistor parameters are: V_{TN} = **0.7 V**, k'_n **= 130** μ**A/V**^{2}, $(W/L)_n$ **= 100** and λ_n **= 0.1 V**$^{-1}$; and the **PMOS** transistor parameters are: V_{TP} **= -0.8 V**, k'_p **= 35** μ**A/V**^{2}, $(W/L)_p$ **= 200** and λ_p **= 0.2 V**$^{-1}$.

(i) **Find** the differential gain A_d. [8 marks]

(ii) It is given that the common-mode gain, A_{cm} for the circuit is **-0.002**. **Calculate** the common-mode rejection ratio, ***CMRR*** **in dB**. [4 marks]

(iii) It is given that the **voltage across the constant current source** I_Q, V_{IQ} **= 0.6 V**. ***Figure* 2** *shows where the* V_{IQ} *is.* **Calculate** the **<u>maximum and minimum output voltage v_o</u>**. State any assumptions.

[8 marks]

<u>Answer for Question 1(b)</u>

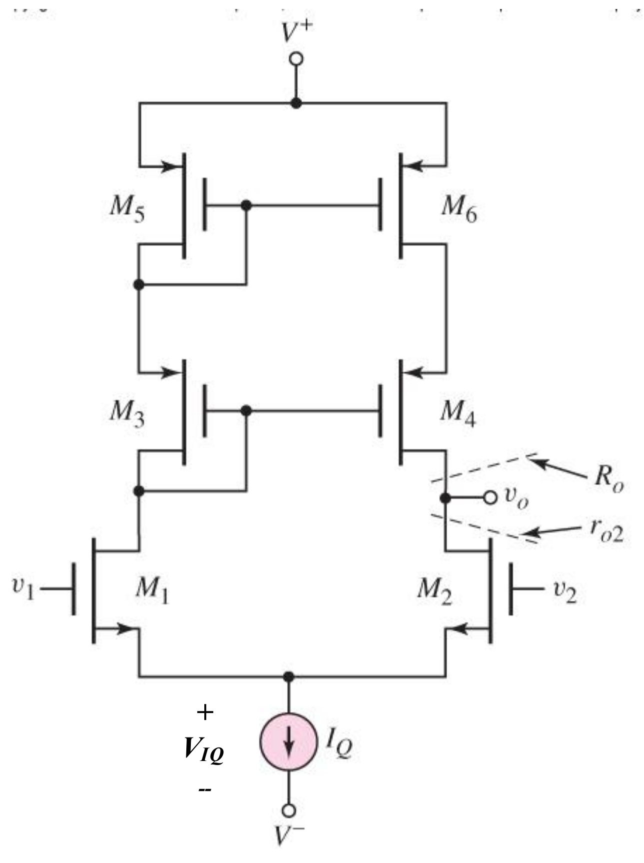


Figure 2

Answer for Question 1(b)

Q1(b)(i)

$$A_d = g_{m1}\left(r_{o2} \| R_o\right) \text{ [1]}$$

$$I_{D1} = I_Q / 2 = I_{D2} = I_{D3} = I_{D4} = I_{D5} = I_{D6} = 1mA/2 = 0.5mA$$

$$g_{m1} = 2\sqrt{K_n I_{D1}} = 2\sqrt{\left(\frac{k_n^{'}}{2}\right)\left(\frac{W}{L}\right)_1 I_{D1}} = 2\sqrt{\left(\frac{130\varepsilon}{2}\right)(100)(0.5m)} = 3.61mA/V \quad \text{[1]}$$

$$r_{o2} = \frac{1}{\lambda_n I_{D2}} = \frac{1}{(0.1)(0.5m)} = 20k\Omega \quad \text{[1]}$$

$$r_{o4} = \frac{1}{\lambda_p I_{D4}} = \frac{1}{(0.2)(0.5m)} = 10k\Omega = r_{o6} \quad \text{[1]}$$

$$g_{m4} = 2\sqrt{K_P I_{D4}} = 2\sqrt{\left(\frac{k_p^{'}}{2}\right)\left(\frac{W}{L}\right)_4 I_{D4}} = 2\sqrt{\left(\frac{35\varepsilon}{2}\right)(200)(0.5m)} = 2.65mA/V \quad \text{[1]}$$

$$R_o = g_{m4} r_{o4} r_{o6} = (2.65m)(10k)(10k) = 265k\Omega \quad \text{[2]}$$

$$A_d = (3.61m)(20k \,\|\, 2.65k) = 67.1V/V \quad \text{[1]}$$

Q1(b) (ii)

$$CMRR = \left|\frac{A_d}{|A_{cm}|}\right| = \left|\frac{67.1}{|-0.002|}\right| = 33550 \quad \text{[2]}$$

$$CMRR_{dB} = 20\log|CMRR| = 20\log(33550) = 90.5dB \quad \text{[2]}$$

Q1(b)(iii)

$$V_o(\max) = V^+ - V_{SD6}(sat) - V_{SD4}(sat) \quad [1]$$

$$V_{SG4} = V_{SG6} \Rightarrow I_{D4} = \left(\frac{k_p^{'}}{2}\right)\left(\frac{W}{L}\right)_4 \left(V_{SG1} + V_{TP}\right)^2$$

$$0.5m = \left(\frac{35\varepsilon}{2}\right)(200)\left(V_{SG4} + (-0.8)\right)^2$$

$$\rightarrow V_{SG4} = 1.178V \quad [1]$$

$$V_{SD4}(sat) = V_{SG4} + V_{TP} = 1.178 + (-0.8) = 0.378V = V_{SD6}(sat) \quad [1]$$

$$V_o(\max) = 3 - 2(0.378) = 2.24V \quad [1]$$

$$V_o(\min) = V_{DS2}(sat) + V_{IQ} + V^- \quad [1]$$

$$V_{GS2} \Rightarrow I_{D2} = \left(\frac{k_n^{'}}{2}\right)\left(\frac{W}{L}\right)_2 \left(V_{GS2} - V_{TN}\right)^2$$

$$0.5m = \left(\frac{130\varepsilon}{2}\right)(100)\left(V_{GS1} - 0.7\right)^2$$

$$\rightarrow V_{GS1} = 0.977V \quad [1]$$

$$V_{DS2}(sat) = V_{GS2} - V_{TN} = 0.977 - 0.7 = 0.277V \quad [1]$$

$$V_o(\min) = 0.277 + 0.6 + (-3) = -2.12V \quad [1]$$

Question 2 **[30 marks]**

The circuit in **Figure 3** shows a simple multi-stage BJT op-amp, **consisting of three different stages**. It is given that for all transistors: β **= 100,** r_o **= 500 kΩ,** g_m **= 5 mA/V,** and r_π **= 3 kΩ.**

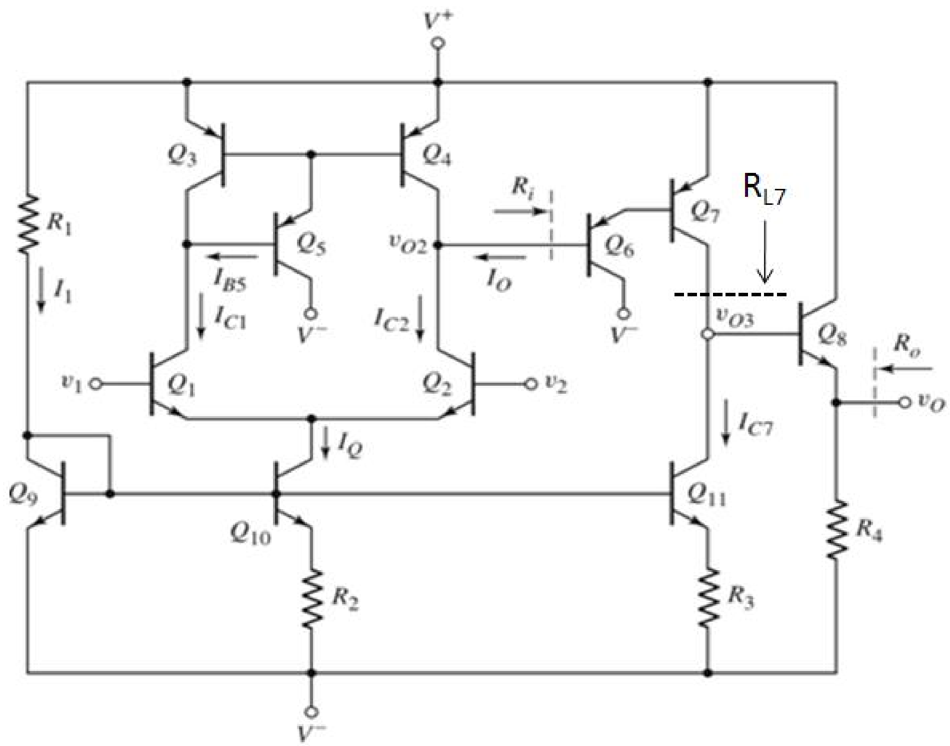


Figure 3

(a) It is also given that R_3 **= 250 Ω** and R_4 **= 10 kΩ**. For Q_7, the **Early voltage** V_A is assumed to be infinite. **Calculate the small signal input impedance** at the collector of Q_7, i.e. R_{L7} as indicated in the **Figure 3.** [12 marks]

(b) **Calculate** the small-signal voltage gain of the gain stage, $A_2 = V_{O3}/V_{O2}$. Given that:

$$V_{O3} = I_{c7}R_{L7}$$
$$V_{O2} = I_{b6}R_i$$

[10 marks]

(c) **Determine** the output resistance of the amplifier, R_o.

[8 marks]

Answer for Question 2

Q2(a)

$$R_{c11} = r_{o11}\left(1 + g_{m11}R_E^{'}\right)$$ [2]

$$R_E^{'} = r_{\pi 11} \| R_3 = 3k \| 250 = 230.8\Omega$$ [2]

$$R_{c11} = r_{o11}\left(1 + g_{m11}R_E^{'}\right) = 500k(1 + (5m)(230.8)) = 1.077M\Omega$$ [2]

$$R_{b8} = r_{\pi 8} + (1+\beta)R_4 = 3k + (101)(10k) = 1.013M\Omega$$ [3]

$\boldsymbol{R_{L7} = R_{c11} \| R_{b8}} = 1.077\text{M} \| 1.013\text{M} = \mathbf{522\ k\Omega}$ [3]

Q2(b)

$$V_{o3} = I_{c7}R_{L7} = (\beta I_{b7})R_{L7} = \beta(1+\beta)I_{b6}R_{L7}$$

$$A_v = \frac{V_{o3}}{V_{o2}} = \frac{\beta(1+\beta)R_{L7}}{R_i}$$ [3, 2]

$$R_i = r_{\pi 6} + r_{\pi 7}(1+\beta) = 3k + (101)(3k) = 306k\Omega$$ [3]

$$A_v = \frac{V_{o3}}{V_{o2}} = \frac{100(101)522k}{306k} = 17229$$ [2]

Q2(c)

$$R_o = R_4 \left\| \left(\frac{r_{\pi 8} + Z}{(1+\beta)} \right) \right.$$ [3]

$Z = R_{c11} \| R_{c7} = R_{c11}$ [1]
$R_{c7} = r_{o7} = \infty$ [1]
$R_{c11} = r_{o11}(1 + g_{m11}R'_E) = 1.077$ MÝ [1]

$$R_o = 10k \left\| \left(\frac{3k + 1.077M}{(101)} \right) \right. = 5.167k\Omega$$ [2]

Question 3 **[30 marks]**

A **class-A** emitter follower biased with a constant current source is shown in **Figure 4**. Assume circuit parameters of V^+ **= 12 V**, V^- **= −12 V**, and R_L **= 50 Ω**. The transistor parameters are β **= 40**, V_{BE} **(on) = 0.7 V,** and v_{CE} **(sat) = 0.7 V**. The minimum current in Q_1 is to be i_{E1} **(min) = 20 mA**.

(a) **Determine** the value of R that will produce the maximum possible output voltage swing. **What** is the value of I_Q? [12 marks]

(b) For output voltage v_O **= 0**, **find** the power dissipated in the transistor Q_1 and the power dissipated in the transistor Q_2. [6 marks]

(c) **Determine** the power conversion efficiency (η) for a symmetrical sine-wave output voltage with a peak value of **10 V**. [12 marks]

Answer for Question 3

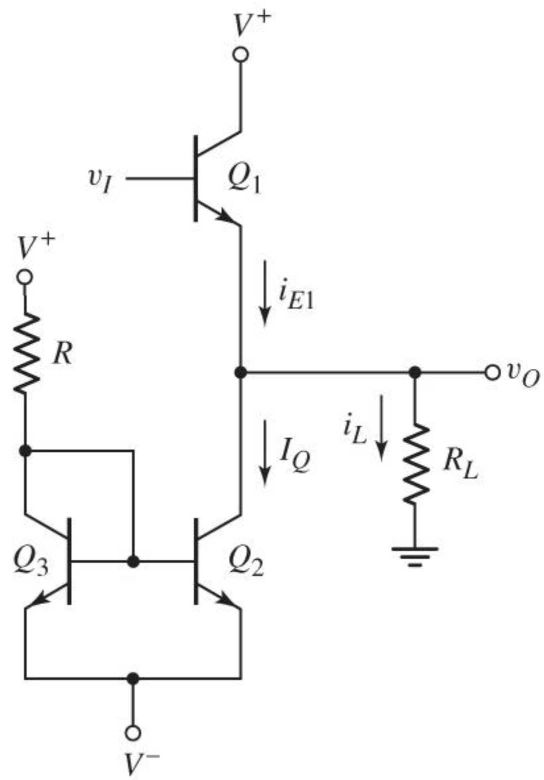


Figure 4

Answer for Question 3

Q3(a)

$$i_{E1} = I_Q + i_L$$

$$i_{E1}(\min) = I_Q + i_L(\min) \ [2]$$

$$i_L(\min) = \frac{v_O(\min)}{R_L} = \frac{V^- + v_{CE2}(\min)}{R_L} = \frac{-12+0.7}{50} = -226mA \ [2]$$

$$I_Q = i_{E1}(\min) - i_L(\min) = 20mA - (-226mA) = 246mA \ [2]$$

$$I_R = I_Q(1 + 2/\beta) \ [2]$$

$$I_R = (246mA)(1 + 2/40) = 258.3mA \ [1]$$

$$R = \frac{V^+ - V_{BE3}(on) - V^-}{I_R} \ [2]$$

$$R == \frac{12 - 0.7 - (-12)}{258.3mA} = \frac{23.3V}{258.3mA} = 90.205\,\Omega [1]$$

Q3(b)

$$P_{DQ1} = V_{CE1}I_{C1} = V_{CE1}I_{E1} = (V^+ - v_O)(I_Q + i_L) = (12-0)(246m + 0) = 2.952W \ [3]$$

$$P_{DQ2} = V_{CE2}I_{C2} = (v_O - V^-)(I_Q + i_L) = (0 - (-12))(246m + 0) = 2.952W \ [3]$$

Q3(c)

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} \times 100\% = [3]$$

$$\overline{P_L} = \frac{[v_P]^2}{2R_L} = \frac{10\times 10}{2\times 50} = 1W \ [3]$$

$\overline{P_S}$ is calculated using power dissipated in Q1 and Q2 :

$$\overline{P_S} = P_{DQ1} + P_{DQ2} = (V^+ - V^-)I_Q = (12 - (-12))(246m) = 5.904W \ [3]$$

$$\eta = \frac{1W}{5.904W} \times 100\% = 16.937\% \quad [3]$$

OR $\overline{P_S}$ is calculated using power dissipated in ALL transistors and R :

$$\overline{P_S} = P_{DQ1} + P_{DQ2} + P_{DQ3R} = (V^+ - V^-)(I_Q + I_R) = (12 - (-12))(246m + 258.3mA) = 12.1032W \ [3]$$

$$\eta = \frac{1W}{12.103W} \times 100\% = 8.262\% \quad [3]$$

BASIC FORMULA FOR TRANSISTOR

BJT

$$i_C = I_S e^{v_{BE}/V_T}\text{; npn}$$

$$i_C = I_S e^{v_{EB}/V_T}\text{; pnp}$$

$$i_C = \alpha i_E = \beta i_B$$

$$i_E = i_B + i_C$$

$$\alpha = \frac{\beta}{\beta + 1}$$

;Small signal

$$\beta = g_m r_\pi$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$r_o = \frac{V_A}{I_{CQ}}$$

$$V_T = 26\text{ mV}$$

MOSFET

;N – MOSFET

$$v_{DS}(\text{sat}) = v_{GS} - V_{TN}$$

$$i_D = K_n[v_{GS} - V_{TN}]^2$$

$$K_n = \frac{k_n'}{2} \cdot \frac{W}{L}$$

;P – MOSFET

$$v_{SD}(\text{sat}) = v_{SG} + V_{TP}$$

$$i_D = K_p[v_{SG} + V_{TP}]^2$$

$$K_p = \frac{k_p'}{2} \cdot \frac{W}{L}$$

;Small signal

$$g_m = 2\sqrt{K_? I_{DQ}}$$

$$r_o \cong \frac{1}{\lambda I_{DQ}}$$